SPECTRUM SHARING OF THE INTERNATIONAL MOBILE TELECOMMUNICATION-ADVANCED AND DIGITAL BROADCASTING IN THE DIGITAL DIVIDEND BAND

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To my beloved mother, father, brothers and sister, and to my only love my wife and to our little princesses Wassan and Leen. Finally to my beloved Jido and dear uncle Mohanna

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ABSTRACT

Increasing demand for wireless services has recently led to a radio spectrum shortage. As the spectrum is a limited and scarce natural resource, it should be used as efficiently as possible. In this thesis, a spectrum sharing study is conducted between the Digital Broadcasting (DB) and International Mobile Telecommunication-Advanced (IMT-A) in the 470–862 MHz band. First, a spectrum sharing simulation model based on statistical methodology is proposed in order to identify the requirements for co-existence between IMT-A and DB systems. The results show that co-existence is possible for a limited number of adjacent channels and for a specific sharing scenario. Next, a spectrum sharing analytical model is developed based on the enhancement of a current coexistence model that has been widely used in spectrum sharing research. From this, it is seen that when the DB bandwidth is 8 MHz, a higher IMT-A bandwidth (20 MHz) can co-exist more feasibly with DB than a lower IMT-A (5 MHz) bandwidth. Moreover, in deploying these systems in urban areas, the required separation distances decrease. We then propose an analytical method for evaluating potential compatibility of cognitive radio (CR) systems. This method computes the allowed maximum in-band (PIB) and out-of-band (POOB) transmission power of a CR system based on a victim receiver interference criterion. The PIB and POOB achieved are 16.41 dB higher and 23.76 dB lower, respectively, than those achieved in the traditional method. Finally, we propose a system called Wireless Link using the Global Communication Channel (WLGCC) that enhances spectrum sharing between DB and CR systems within the licensed 470–790 MHz band. The results show that WLGCC does not degrade existing DB service while reliably transmitting information on vacant frequency bands to the CR.

ABSTRAK

Permintaan yang semakin meningkat bagi perkhidmatan wayarles baru-baru ini mengakibatkan spektrum radio tidak mencukupi. Oleh sebab spektrum adalah sumber yang terhad, penggunaannya yang efektif adalah perlu. Dalam tesis ini, satu kajian berkenaan perkongsian spektrum antara sistem Penyiaran Digital (DB) dan sistem Lanjutan-Telekomunikasi Mobile Antarabangsa (IMT-A) telah dijalankan bagi julat frekuensi 470-862 MHz. Pertama, model simulasi perkongsian spektrum menggunakan metodologi statistik dicadangkan untuk mengenal pasti syarat-syarat bagi membolehkan kewujudan bersama sistem IMT-A dan sistem DB. Hasil kajian menunjukkan bahawa kewujudan bersama boleh dijalankan untuk bilangan saluran bersebelahan yang terhad dan senario perkongsian tertentu sahaja. Seterusnya, satu model analisis perkongsian spektrum dihasilkan daripada penambahbaikan kepada model sistem kewujudan bersama sedia ada yang digunakan secara meluas dalam penyelidikan perkongsian spektrum. Daripada analisis ini, dapat diperhatikan bahawa apabila jalur lebar sistem DB adalah 8 MHz, sistem IMT-A dengan jalur lebar lebih tinggi (20 MHz) adalah lebih sesuai untuk wujud bersama dengan sistem DB dibandingkan dengan sistem IMT-A yang mempunyai jalur lebar yang lebih rendah (5 MHz). Selain itu, untuk pengoperasian kedua-dua sistem ini di kawasan bandar, didapati jarak pemisahan yang diperlukan menjadi lebih pendek. Kajian ini kemudiannya mencadangkan satu kaedah analisis untuk menilai kesesuaian sistem radio kognitif (CR). Kaedah ini mengira kuasa penyiaran dalam jalur (PIB) dan di luar jalur (POOB) maksimum berdasarkan kriteria gangguan penerima mangsa. Nilai kuasa PIB adalah 16.41 dB lebih tinggi, dan 23.76 dB pula lebih rendah bagi POOB, jika dibandingkan dengan kaedah konvensional. Akhir sekali, kajian ini mencadangkan satu sistem yang dipanggil Laluan Wayerles menggunakan Saluran Komunikasi Global (WLGCC) yang mampu meningkatkan perkongsian spektrum antara sistem DB dan sistem CR bagi julat frekuensi berlesen 470-790 MHz. Hasil kajian menunjukkan WLGCC tidak mengganggu perkhidmatan sistem DB sedia ada malahan dapat menghantar maklumat dengan baik kepada sistem CR menggunakan saluran frekuensi yang tidak dipakai.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2G	-	Second Generation
3G	-	Third Generation
4G	-	Fourth Generation
ACIR	-	Adjacent Channel Interference Ratio
ACLR	-	Adjacent Channel Leakage Ratio
ACS	-	Adjacent Channel Selectivity
AD	-	Antenna Discrimination
A-MCL	-	Advanced Minimum Coupling Loss
APT	-	Asian Pacific Telecommunity
ASO	-	Analogue Switch Off
ATSC	-	Advance Television System Committee
BS	-	Base Stations
C/I	-	Carrier-to-Interference Ratio
C/N	-	Carrier-to-Noise Ratio
C/N+I	-	Interference-to-Interference-Pulse-Noise Ratio
CC	-	Current Coexistence
CEPT	-	Conference for Postal And Telecommunity
CL	-	Clutter Loss
COFDM	-	Coded Orthogonal Frequency Division Multiplexing
CR	-	Cognitive Radio
CRS	-	Cognitive Radio System
DB	-	Digital Broadcasting
dBc		Decibels relative to the carrier
DB-SS	-	DB Subscriber Station
DD	-	Digital Dividend

DL	-	Downlink
DTMB	-	Digital Terrestrial Multimedia Broadcast
DTTB	-	Digital Terrestrial Television Broadcasting
DVB-H	-	Digital Video Broadcasting – Handled
DVB-T	-	Digital Video Broadcasting – Terrestrial
EC	-	Enhance Co-existence
E-MCL	-	Enhanced Minimum Coupling Loss
EM	-	Electromagnetic Fields
ESM	-	Exclusive Spectrum Management
E-UTRA	-	Evolved-UMTS Terrestrial Radio Access
FCA	-	Frequency Channel Assignment
FCC	-	Federal Communication Commission
FDD	-	Frequency Division Duplex
FDMA	-	Frequency Division Multiple Access
FS	-	Fixed Service
FSO	-	Frequency Separation Offset
GB	-	Guard Band
GCC	-	Global Communication Channel
GE-06	-	Geneva Agreement -2006
GE-89	-	Geneva Agreement-1989
GLD	-	Geolocation Database
GPS	-	Global Positioning System
HDTV	-	High Definition Tv
HSM	-	Hierarchical Spectrum Management
I/N	-	Interference-to-Noise Ratio
IMT-A	-	International Mobile Telecommunication–Advanced
ISM	-	Industrial, scientific, and medical
ITU	-	International Telecommunications Union
IP	-	Internet Protocol
ISDB-T	-	Integrated Service Digital Broadcasting – Terrestrial
LAN	-	Local Area Network

LOS		line-of –sight
LTE	-	Long Term Evolution
LTE-A	-	Long Term Evolution – Advanced
MCL	-	Minimum Coupling Loss
MIMO	-	Multiple Input And Multiple Output
MPEG	-	Moving Picture Experts Group
NB	-	Necessary Bandwidth
OFDM	-	Orthogonal frequency division multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access
OOK	-	On Off Shift Keying
OSA	-	Opportunistic Spectrum Access
PIB	-	Power In-Band
POOB	-	Power Out-Of-Band
PIB-5		Power In-Band for 5 km away from DB receiver
PIB-10		Power In-Band for 10 km away from DB receiver
PR	-	Protection Ratio
PSD	-	power spectral density
PSTN	-	Public Switched Telephone Network
RF	-	Radio Frequency
RN	-	Reference Network
RPC	-	Reference Planning Configures
RRC-06	-	Regional Radiocommunication Conference-2006
SC	-	Spectrum Common
SEM	-	Spectrum Emission Mask
SNF	-	Single Frequency Network
SS	-	Subscriber Station
TDD	-	Time Division Duplex
TDMA	-	Time Division Multiple Access
TVWS	-	Television White Space
UE	-	User Equipment
UHF	-	Ultra High Frequency
UL	-	Uplink
UWB	-	Ultra Wide Band

WiMAX	-	Worldwide Interoperability for Microwave Access
WLGCC	-	Wireless Link Based On The Global Communication Channel
WLGCC-TX	-	WLGCC Transmitter
WRC-07	-	World Radio Conference-2007
WRC-12	-	World Radio Conference-2012
ZGB	-	Zero Guard Band

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The use of wireless applications is growing daily. As the spectrum is a limited viable resource, with new systems needing to share licensed frequencies with existing services, spectrum sharing and compatibility studies have become emerging research topics. Results of such studies can help guarantee that, within a shared frequency band, new systems can operate without performance degradation while existing services are protected. Such outcomes are considered necessary in order to save costs by preventing expected harmful interference impacts between new and former systems.

This thesis focuses on co-existence and spectrum sharing between the up-and-coming mobile communications system known as the International Mobile Telecommunication-Advanced (IMT-A) and the Digital Broadcasting (DB) services within the 790–862 MHz sub-band of the congested ultra high frequency (UHF) band. By developing various co-existence and spectrum sharing models, this study aims to develop a co-existence requirement for these two services when sharing a portion of the spectrum. Additionally, the use of cognitive radio (CR) to enhance spectrum sharing between these two services is investigated.

The introduction of DB with high spectral efficiency has helped to trigger a phasing-out of analog broadcasting. By using advanced technologies such as coding and compression, DB can more efficiently use the UHF spectrum; while analog broadcasting requires 8 MHz of bandwidth per channel, DB can deliver up to 14 channels over the same 8 MHz. This efficient use of spectrum has freed up a segment of the UHF band called the digital dividend (DD) band, resulting in a previously unthinkable availability of free spectrum within the UHF band. Since implementation of the Stockholm Plan in 1961, the lower UHF band (i.e., 470–862 MHz) had been reserved for analog broadcasting [1, 2]. However, at the latest Regional Radio Communication Conference in 2006 (RRC-06), all participating countries were given a mandate to migrate from analog to DB no later than 2015. This analog switch off (ASO) is extended to 2020 for countries that cannot meet the 2015 deadline, as well as to countries not present at RRC-06 [3].

The evolution of the mobile systems from voice-only to multimedia service has led to a corresponding increase in demand on the radio spectrum. The IMT-A is the next generation of mobile telephony standard [1] that aims to provide more multimedia service at higher quality; it will be available after the next World Radio Conference-2012 (WRC-012). The two main challenges in implementing IMT-A, which exemplify the demand created on the spectrum by such new technologies, are supporting a bandwidth of up to 100 MHz per channel and accommodating a high data rate. To cope with the introduction of both IMT-A and a new terrestrial broadcasting platform (i.e., DB), the World Radio Conference-2007 (WRC-07) passed two unanimous resolutions concerning the 790–862 MHz band: the first of these (224 of WRC-07) stated the intention of the administrations to protect the existing broadcasting system from the mobile system, while the second (794 of WRC-07) allocated the 470–806/862 MHz band to both mobile and broadcasting services as co-primary basis starting in 2015. Furthermore, the resolution (794 of WRC-07) requested that studies of sharing between the two services be conducted [4]. Based on this, a wide range of research has been conducted to investigate the preferred frequency channel assignment (FCA) of mobile services within the DD band. As of this time, two FCA proposals have been submitted to the International Telecommunications Union (ITU): the European Harmonized FCA, submitted by the

European Conference of Postal and Telecommunications Administrations (CEPT) in 2008 for Region 1 (Europe and Africa) [5] and the Asia–Pacific Telecommunity (APT) FCA proposal for Region 3 (Asia and the Pacific), submitted in 2010 [6].

1.2 Research Motivation

As the ITU has assigned the 470–862 MHz band to terrestrial DB and the IMT-A service will operate in the 791–862 MHz band [7], it is evident that these two services must share a spectrum, which might lead to performance degradation. As a result, studies of interference between the two services are required in order to ensure primary service protection (i.e., DB reception) and to maintain the quality of service of the newly introduced system (i.e., IMT-A). Such studies are needed to quantify possible compatibilities between the two services and to propose practical guidelines for efficient spectrum usage and reliable services.

Until all of the ITU-participating countries switch to DB (which is expected to occur between 2012 and 2020 [3]) and the commercial deployment of IMT-A (expected in 2015 [8]), the topic of spectrum sharing will be an important and challenging one between the two services. All research opinions, recommendations, and results will be considered as input notes to the upcoming WRC-12 and WRC-15, demonstrating that studies designed to find the most efficient approaches for utilizing the shared radio spectrum still represents an open area of research. One of the challenges facing the ITU is that spectrum sharing studies are difficult to standardize globally, as each country has its own spectrum planning scheme. Thus, each country must conduct its own spectrum sharing studies.

Although several studies of spectrum sharing between IMT-A and DB have already been conducted within the DD band and other bands, as shown in Appendix B, this study motivation for research is to further develop expected spectrum sharing scenarios as well as new spectrum sharing models. In addition, this study will investigate enhancement of the existing model of spectrum sharing between the two systems.

1.3 Problem Statement

IMT-A and DB services will need to share the existing spectrum while operating in a compatible manner. Both co-channel and adjacent channel interference may occur between the two services, with co-channel interference certain to occur between two territories or countries. If, for example, country A completes the ASO phase and deploys mobile services in the 790–862 MHz sub-band, while neighboring country B is in a transition period of switching from analog to DB and still using the 790–862 MHz sub-band for broadcasting services, then co-channel interference will occur in radio communication between the two countries. Likewise, adjacent channel interference may occur in one country between two services operating within the same geographical region. For instance, if a country has deployed mobile service in the 790–862 MHz sub-band where DB service is already operational in the 470–790 MHz band, then these two systems will experience adjacent channel interference with each other even though they are separated in the frequency domain. Such interference is more challenging when both services are active and cover the same area (i.e., a co-cited situation). Thus, the development of analytical and simulation models is needed to assess possible interference between the two systems and to find their necessary compatibility requirements. Enhancement of spectrum sharing between two systems can be considered as a viable solution to interference.

1.4 Research Objectives

The objective of this study is to evaluate the performance of a primary service (i.e., DB) when a new service (i.e., IMT-A) is introduced into the 790–862 MHz sub-band, and vice versa. This will be done by investigating expected sharing scenarios when both services are deployed in the same geographical area (i.e., adjacent channel sharing scenarios) as well as when they share a frequency in two different geographical locations (i.e., co-channel channel sharing scenarios). The results of these assessments will set co-existence requirements for deploying both services. This result will also help fulfill the ITU-R study request concerning the sharing of these two services, demonstrating that spectrum sharing enhancement is required to maximize utilization of the spectrum.

Based on the statement of the research problem, the objective of the study can be broken down as follows:

- To investigate the interference impact of introducing the new mobile standard IMT-A in order to ensure protection of the DB service. The results of this will set co-existence requirements, including the required minimum separation distance and the width of the frequency guard band;
- To carry out a performance measurement of the new service (IMT-A) as it is affected by the primary service in order to find the required separation distance and guard band; and
- To investigate CR as a solution for enhancing spectrum sharing between IMT-A and DB within the DD band.

1.5 Research Scope

To carry out these research objectives, the scope of the study must include an identification of the system parameters of both services, as well as recommendations as to how each service should be deployed in different areas. Statistical methodology will be utilized to assess interference and evaluate performance. The IEEE 802.16m Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution-Advanced (LTE-A) systems will be used to represent the IMT-A service, while Digital Video Broadcasting-Terrestrial (DVB-T) will be used as a DB service. Various CR techniques will be investigated and applied in order to optimize spectrum sharing within the 790–862 MHz band.

The scope of the study covers the following:

- Literature review of current research, technical reports, and recommendations that have been published regarding the co-existence of IMT-A and DVB-T;
- Determination of the technical parameters of both mobile and DB services, along with their propagation models, interference criteria, and future frequency sharing scenarios;
- Determination of co-existence methodologies in order to evaluate the interference effect. For this, both mathematical and simulation models are considered;
- Development of an analysis tool to assess co-existence between DB and IMT-A;
- Investigation of CR spectrum sharing methods;
- Development and modeling of a proposed novel method for enhancing spectrum sensing techniques in order to achieve optimal spectrum usage within the UHF band; and
- Proposal of a system to enhance the spectrum sharing model of CR.

1.6 Significance and Contribution of the Research Work

The main significance of this research is that it assesses ways to maximize the utilization of the limited radio spectrum resource. Furthermore, as no IMT-A system will be deployed until 2015 [8], the findings of this research will be important to member countries of the ITU, as it will allow them to predict future scenarios and the consequences of deploying both services. The results of this study will provide recommendations for deployment of IMT-A and requirements for protection of the DB service. The study also introduces new co-existence models based on mathematical and simulation modeling. Finally, it introduces a new spectrum sensing sharing model and a proposed system to enhance spectrum sharing methods in the CR. Together, these contributions will be useful for the deployment of services within the same or adjacent geographical areas in such a manner that primary service is protected and higher spectrum utilization is achieved.

The contributions of this research are as follows:

1. An analytical model to evaluate interference from IMT-A orthogonal frequency division multiplexing (OFDM) based on DB broadcasting-coded OFDM (COFDM) and using statistical methodology is developed (Chapter Four, Section 4.4);
2. An analytical model to evaluate the interference between mobile and broadcasting services, and vice versa, based on the spectrum emission mask (SEM) of the interferer and the interference-to-noise (I/N) ratio of the victim receiver is developed using statistical methodology (Chapter Four, Section 4.5);
3. A simulation model based on statistical methodology is proposed to evaluate possible interference for DB victim receivers resulting from implementation of the ITU digital plan as well as for mobile service resulting from the European FCA (Chapter Four, Section 4.6);
4. A CR spectrum sensing model to enhance spectrum sharing between IMT-A and DB within the DD band is developed (Chapter Five, Section 5.5); and
5. A new system for enhancing spectrum sensing and geo-location database (GLD) sharing methods in CR is introduced (Chapter Six, Section 6.3).

1.7 Organization of the Thesis

In compliance with the theoretical and practical aspects of the study, this thesis consists of eight chapters, each providing a detailed discussion of the respective issues.

- Chapter One provides an introduction and background to the research, in order to demonstrate the importance of the topic and shape the lines of argument in the research. Following this, the motivation for research, statement of the problem, objectives of the research, research scope, significance of the study, and, finally, the thesis outline are presented.

- The theory and the literature review are presented in Chapter Two, which provides the theory behind the relevant work as well as recommendations relating to DB and IMT-A systems, co-existence requirements, spectrum sharing methods, and related work. As co-existence between the new mobile service (IMT-A) and the new broadcasting platform DVB-T services is a currently popular topic for research, the literature review will proceed until the writing of the final draft of this thesis. The chapter also reviews the related studies in co-existence and spectrum sharing.
- In Chapter Three, the methodologies used to achieve the results of this study are provided. These are divided into five parts: a literature review, development of an analytical model of a sharing technique to evaluate the co-existence requirements between IMT and DB services, investigation of the CR as a spectrum sharing technique, enhancement of CR spectrum sharing methods, and proposal of a new system to enhance CR spectrum sharing methods.
- Chapter Four provides a detailed description of co-existence between IMT-A and DB within the DD band. This chapter represents the core of the research conducted to formulate the current problem of interference between these two systems. Statistical methodology is used to understand the conditions for compatibility between the systems, and the results of this chapter will clarify and call attention to the consequences of interference impact between the two systems when they share the 790–862 MHz spectrum.
- In Chapter Five, CR spectrum sharing techniques for enhancing the co-existence between IMT-A and DB within the DD band are investigated. The chapter provides details of current spectrum sensing methodologies and introduces a model for enhancing CR system spectrum sensing methods.
- In Chapter Six, a new system for enhancing the CR spectrum sharing model is proposed. Additionally, this chapter provides arguments and discussion pertaining to the new system. A justification of the utility of the new system and sharing scenarios to investigate its validity are provided.
- Chapter Seven provides research results and discussion. An extensive analysis of co-existence and spectrum sharing methodologies is conducted.

- Finally, Chapter Eight is devoted to the overall conclusions of the research. This is followed by a discussion of future work needed to enhance co-existence between DB and IMT-A system.

APPENDIX A

PUBLICATIONS

Journal Papers

1. **Walid A Hassan**., *et al.* Spectrum Sharing Method for Cognitive Radio in TV White Spaces.KSII Transactions on Internet and Information Systems (TIIS). 2012. 6 (8): 1894-1912.

2. **Walid A. Hassan**. A Spectrum Sharing Model for Compatibility between IMT-Advanced and Digital Broadcasting.KSII Transactions on Internet and Information Systems (TIIS). 2012. 6 (9): 2073-2085.

Conference Papers

1. **Walid A. Hassan**, Tharek Abd Rahman "Compatibility between Cognitive Radio and the Terrestrial Digital Broadcasting Services in the Digital Dividend Band". *Proceedings of PIERS 2012 in Kuala Lumpur*, Malaysia. 27-30 March, 2012.)

2. **Walid A. Hassan**, Yusuf Abdulrahman, Tharek Abd Rahman "The Digital Dividend Spectrum in Asia.". *Proceedings of PIERS 2012 in Kuala Lumpur*, Malaysia. 27-30 March, 2012.)

3. **Walid A. Hassan**, Tharek Abd Rahman “Compatibility between the IMT-A service with digital broadcasting in the digital dividend band”. ICWCA 2012, 8 - 10 October 2012.Kuala Lumpur, Malaysia. IEEE/IET. (Accepted, in press)

4. Yassir A. Ahmad, **Walid A. Hassan**, Tharek Abd Rahman. Studying Different Propagation Models for LTE-A System.. *The International Conference on Computer & Communication Engineering 2012, ICCCE 12*, Kuala Lumpur, Malaysia. July 12. IEEE (Accepted) (*In Press).*

5. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman. Optimizing the coexistence between HAPS platform and terrestrial system in 5.7GHz band. *The International Conference on Computer & Communication Engineering 2012, ICCCE 12*, Kuala Lumpur, Malaysia. July 12. IEEE (Accepted) (*In Press).*

6. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman .Enhancement of Coexistence between HAPS and Terrestrial System in 5.8 GHz Band *Proceedings of PIERS 2012 in Moscow*, Russia. 19-23 August, 2012. (Accepted). (*In Press)*

7. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman .Utilizing ATPC Scheme to Facilitate Sharing between HAPS and Terrestrial in 5.8 GHz Band *Proceedings of PIERS 2012 in Moscow*, Russia. 19-23 August, 2012. (Accepted). (*In Press)*

8. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman .Applicability of DCA in HAPS-based Systems in 5850--7075 MHz Band . *Proceedings of PIERS 2012 in Moscow*, Russia. 19-23 August, 2012. (Accepted) (*In Press)*